Decentralized Order Books for Global Financial Markets

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1 Challenge

Current financial order books and subsequent Electronic Communications Network trades require investors to submit orders to centralized exchanges which allow buyers and sellers to meet at market asset prices. This creates an unnecessary trusted third party between investors which then reports exchange information to the market in centralized and often manipulated or delayed ways.

Furthermore, central brokers receive Payment For Order Flow or other commissions from market makers for equities, bonds, commodities, futures, options, (crypto)currencies and other closed-end financial products. These market makers profit on spread when orders are not internalized, fulfilled on dark pools, or executed directly on exchanges on behalf of a broker or clearing house. This creates centralized incentives to fulfill client orders at below-fair-market prices or through poor execution routes, as shown by large unnamed firms throwing away hundreds of millions in shareholder value to rack in PFOF, resulting in recent SEC lawsuits and settlements against major brokers.

Because centralized order books require a trusted third party to facilitate transactions and take on inherent operations, margin, and fulfillment hard costs, these institutions naturally command fees that lower effective retail shareholder portfolio value over time and complicate asset exchanges which further leads to higher operation costs. These additional expenses are passed on to retail investors.

Many orders in the books are hidden from the overall market and often invisible for average investors. This has recently lead to massive lawsuits against major market firms using uncoordinated centralized National Best Bid and Offer (order book) asset prices to enable large-scale predatory trading. This kind of behavior endangers any investor while creating massive profits for those playing on opaque order book market data.

Because of these woes in centralized order books, the authors believe that a means to propose financial transactions without a trusted third party with instant public recognition will decrease the fundamental barrier to entry into finance by lowering inherent fees and opaqueness in market players. Therefore, this Paper will explore a means to create a global order book for any given asset that anyone can propose transactions to which are rapidly validated. Once orders are confirmed, they must be filled, which goes beyond the scope of this paper. See the conclusion for more details and follow-up.

2 Background Information

Stocks, Bonds, & Cryptocurrencies

The authors assume a basic understanding of paper assets, returns, leverage, secondary markets, public investing infrastructure, options, futures, fiat characteristics, commodity fulfillment, cash settlement, contract margin, and pricing mechanisms once a security is issued. For more information on the former topics, see a free investing seminar series **here.**

Order Books

The authors assume a basic understanding of order books and underlying transactions in asset markets. The reader is assumed to know how level 2, market orders, ECN limit orders, market depth, spreads, arbitrage, and trade execution function and are related in an orderly financial market. For more information on the former topics, see Julien Schroeter's thesis *Limit Order Book reconstruction, visualization and statistical analysis of the order flow* **here,** paying close attention to execution venues.

Stock Issuance & Transfer Agents

The authors assume a basic knowledge of Initial Public Offerings, Initial Coin Offerings, Initial Security Token Issuance, and centralized stock transfer agents. For more information on the former topics, see Craig Dunbar's *Factors affecting investment bank initial public offering market share* **here.**

For more information on transfer agents, see *Responsibilities and Liabilities of the Transfer Agent and Registrar* by Fredrick Behrends and Shelden Elliott **here,** paying close attention to paragraph two about central ledgers. These services cost companies hundreds of millions annually, expenses that are passed onto operating costs and eventually clients (you).[1]

Terminology

"Investing," "stockpiling," "going long," "entering short," "closing a position," "writing," "issuing," "buying," "selling," and all similar investing terms will from this point forward be referred to as **trades** by the authors no matter their intention, time horizon, risk profile, or originating party. Our work is intended to function with users and smart contracts alike.

Acronyms

For more information on these acronyms or a deeper understanding of personal finance in general, see the free investing course linked above.

- **Payment For Order Flow:** Payment from a central third-party market maker to a broker-dealer in exchange for unfulfilled trades. Once order flow is sold, the buying firm must fulfill the trade at any price within the NBBO range through internalization or on centralized ECNs. The fill price at the winning market marker is your fill price

[1] **One predominant transfer agent that acquired Wells Fargo's shareholder services two years ago**

as a client sending an order. This practice was pioneered by Bernard Madoff, and essentially all current brokers get compensated for orders this way. The revenues central brokers receive from PFOF are publicly disclosed in quarterly SEC Rule 606 Report Disclosures.

- **Securities & Exchange Commission:** The American government agency created to regulate secondary asset markets in the Securities Exchange Act of 1934. The financial regulations adopted by the SEC are enforced globally by the agency due to the central nature of American financial markets in the global economy.

- **National Best Bid & Offer:** The highest unfilled bid price and lowest unfilled ask price for a given asset from national central-exchange order books (excluding low-liquidity bonds).

- **Electronic Communications Network:** A centralized order book with buyers and sellers willing to pay certain prices for an given asset. There are hundreds of these central networks that all record unfilled limit orders routed to them. When trades are executed, ECNs take a transaction fee just like any other exchange. ECNs also implement a maker-taker pricing model coined by Joshua Levine where broker-dealers (or equivalent in other asset markets) are charged or paid money when 'making' or 'taking' liquidity from a book, which varies from ECN to ECN. Making liquidity is the equivalent of sending a limit order within the NBBO range. Taking liquidity is the equivalent of sending a market order or aggressive limit order that fills many quotes from the ECN near the NBBO. Many of these ECNs are controlled by central exchanges and their level 2 and time and sales are reported through central exchanges. Other ECNs are controlled by private firms, most often acting as dark pools or otherwise not reporting realtime quotes to exchanges or subsequently the NBBO.

- **Depository Trust & Clearing Corporation:** A private company owned largely by many central exchanges that clears trades by swapping money and assets between counterparties after confirmation for a fee. Similar to the Clearing House Electronic Subregister System, Fixed Income Clearing Corporation, etc. for all global equity and bond markets. All of these firms are highly regulated and act as irremovable central trade settlement firms after trades execute in centralized markets. The authors will use DTCC in place of the many firms that fulfill trades after they are filled in the order book with the understanding that (crypto)currency markets do not use settlement firms in general. Do not confuse asset settlement with trade clearing houses which act as vital centralized intermediary trade-facilitators between buying and selling broker-dealers. These clearing houses function and are compensated primarily for their participation to mitigate central counter-party trade risk, not asset-swap fulfillment after trades.

- s.t. **:** such that

- $\forall$ **:** for all

- $\therefore$ **:** therefore

3 Centralized Financial Markets

3.1 Centralized Order Books

3.1.1 Where We're Starting

The single most important factor in opening financial investment opportunities up to masses of people is liquid, accessible financial order books. When order books are liquid, trades execute smoothly and investing becomes geometrically more profitable. When trades are simple to access on clear public order books, trades become straightforward to execute and account for. Centralized order books are extraordinarily liquid almost entirely in financial assets and sectors that are profitable for third-party central market makers to trade spreads in. However, order book liquidity dries up when markets get too volatile or half of all potential trades are hidden from investors on unreported liquidity pools. Furthermore, the sheer number of middlemen for a vast bulk of standard retail orders to pass through significantly hinders execution speed and quality. When investors have to ping through multiple rounds of internalization, PFOF group-trade bundling and sale, and optimal maker-taker kickback calculations, the end trader often loses out on opportune fills while big central institutions profit from these inefficiencies.

Furthermore, order books are often completely unavailable to many potential new investors simply due the massive amount of government regulations governing centralized exchanges and subsequent asset markets. These regulations block out masses of people from entering the market simply because they do not and may never have a Social Security Number or US taxpaying address. When global investors are blocked from American financial markets, institutions are not just denying foreign families the ability to participate and grow their wealth in the largest powerhouse economy on planet Earth. **These institutions fundamental lower the amount of investors and therefore liquidity in centralized order books because of plummeted financial-market accessibility**. When we withhold American assets from foreign investors through red tape and difficult-to-access order books, everyone suffers.

3.2 Centralized Exchange Equity Order Books

Before we get into order processing, it is vital to deconstruct the convoluted process incoming orders go through when they reach a centralized exchange. Please notice in the diagram below that almost every arrow pictured represents some kind of financial firm, massive infrastructure, or human workload that must be completed each and every day during and after market hours. For example, centralized trade confirmation and reporting alone takes thousands of full-time workers grinding away to "automatically" settle trades. The ECN networks detailed do not hire managers that get free lunches down on Wall Street. Each and every factor in the below diagram has a very large cost, and these expenses eventually get passed on to the everyday investor. The authors believe that the best way to remove these costs and complications is through decentralized order books which we will detail later. For now, embrace the complexity of traditional central order execution and look closely at how trades and subsequent information flows through traditional firms to actually reach the NBBO and public time and sales through centralized equity order book consolidation:

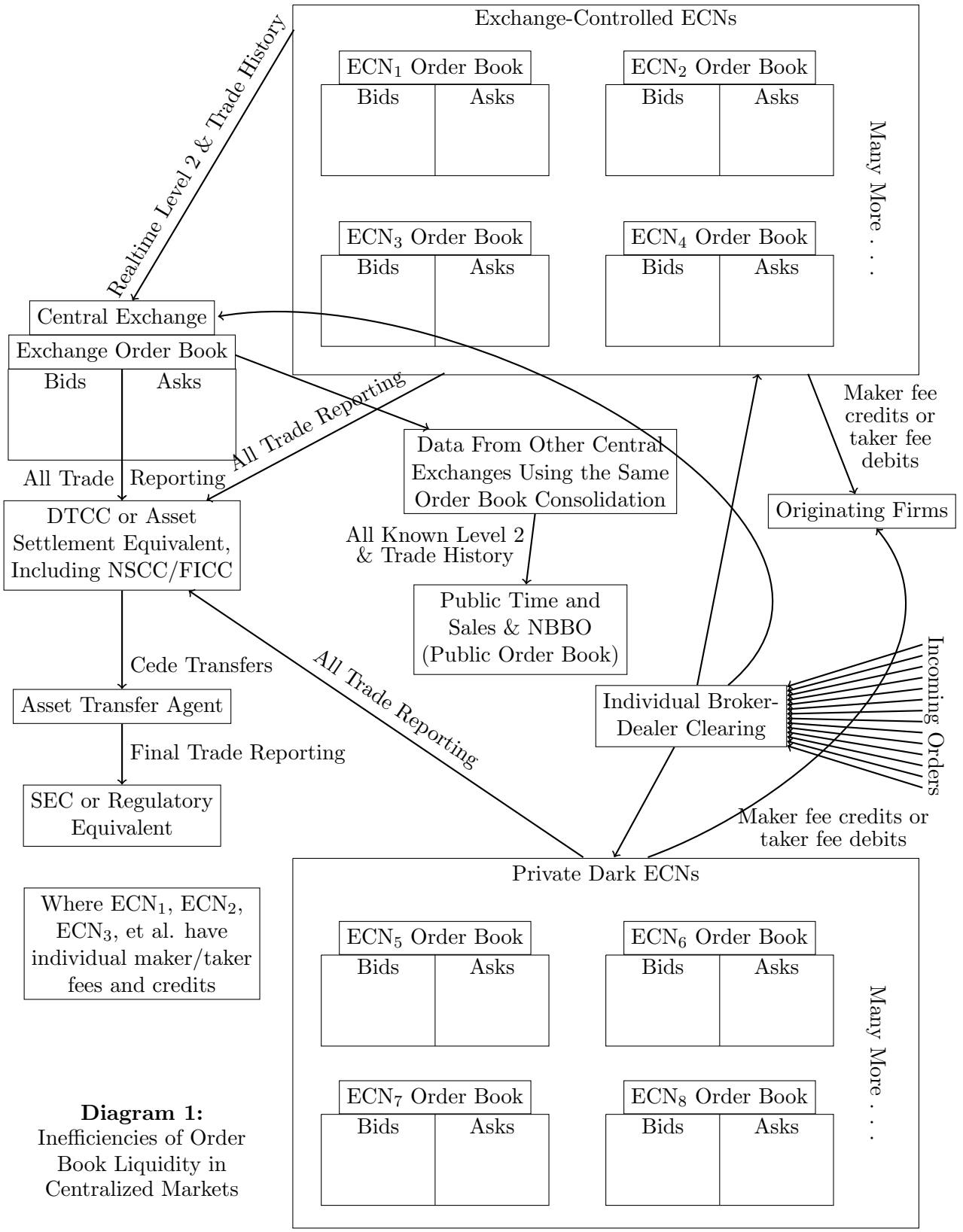


Diagram 1:
Inefficiencies of Order Book Liquidity in Centralized Markets

At first, massive amounts of orders flow in from broker-dealers routing trades on behalf of clients. These trades must first go through a clearinghouse s.t. all counterparty risk is held against institutions that put down big deposits at the exhange. This means that brokers are held liable for their delinquent clients, rather than individuals having responsibility over the validity of their own investments. Once trades are matched, resulting funds and assets then have to flow back through these clearinghouses to the brokers that represent their clients, rather than individuals just trading directly with person on the other end(s) of their transaction(s) when filled (partially filled with multiple other market participants). This adds redundant middlemen, costs, complexity, and sluggishness to trade execution.

3.2.1 For Market Orders

After order flow make it through clearing, central brokers must decide instantaneously where to send your trades. This means taking the time to (i) check best bids and offers on private ECNs, (ii) check best bids and offers on exchange ECNs, (iii) check best bids and offers on exchange order books, (iv) compare given quotes to the NBBO, (v) determine the best available price, (vi) and calculate the best route to send a trade through given a tie in prices based on the most profitable maker-taker model. All these steps open up time for underlying asset prices to move, execution quality to decrease, liquidity to leave the market, and spreads to increase. Brokers could care less, but this process crushes the fill quality of investors daily.

3.2.2 The Obvious Problem With Maker-Taker

ECNs in centralized exchanges charge and pay maker-taker fees to the brokers that send order flow to an ECN order book. For instance, ECN_1 may charge brokers to add liquidity to the order book and pay brokers to remove liquidity, whereas ECN_3 may charge brokers to remove liquidity and pay brokers to add liquidity. While maker-taker pricing schemes for ECNs are great at attracting and retaining ECN liquidity in a market with many competing ECN order books, they are terrible for the end investor. Essentially all maker-taker models have a net debit affect on the collective order flow through an ECN. This creates another unnecessary middleman cost for investors and, more significantly, **forces brokers to consider their potential profit for where they route trades when executing your order, thereby increasing net execution time.**

3.2.3 For Limit Orders

Once limit orders make it though clearing, brokers essentially only have to consider maker-taker fees and obviously exchange order book fees. We will not talk much about actual exchange order books because the fees to execute on an exchange are almost always significantly higher than on an ECN or other alternative trading systems. These exchanges mimic the order books of ECNs with the simple difference that they carry higher exchange fees while obviously being directly tied to exchange level 2. With that said, a vast majority of trades happen on dark pools or similar centralized ECNs when routed to central exchanges $\therefore$ clearing firms are incentivized to route orders to books with the highest rebates for the given order type, given enough liquidity and price-matching across books.

3.2.4 Trade Reporting

The most important takeaway from Diagram 1 besides all the fee-filled intermediaries of trade processing is that trades very often end up trading off the national published order book even though an order makes it to a central exchange. First and foremost, the NBBO comes from central exchanges reporting the realtime quotes and time and sales **they know of.** Thanks to private ECNs which are only required to report to the SEC and settlement houses, exchanges often know only of a sliver of actual trading volume and execution ranges. To fully understand how trades actually affect the public order book, let's look deeper into how volume flows through the Big Three.

3.3 Your Fulfillment Process

Today, orders for an exceedingly vast majority of asset trades occur via centralized (i) brokers, (ii) exchanges, and (iii) market makers (or primarily the Big Three "broker-dealers"). The authors assume a basic understanding of these three financial instituted alongside (i) internalization, (ii) order matching, (iii) and fulfillment incentives. In essence, these three "broker-dealers" are financially incentivized to fulfill financial asset orders according to the following diagram:

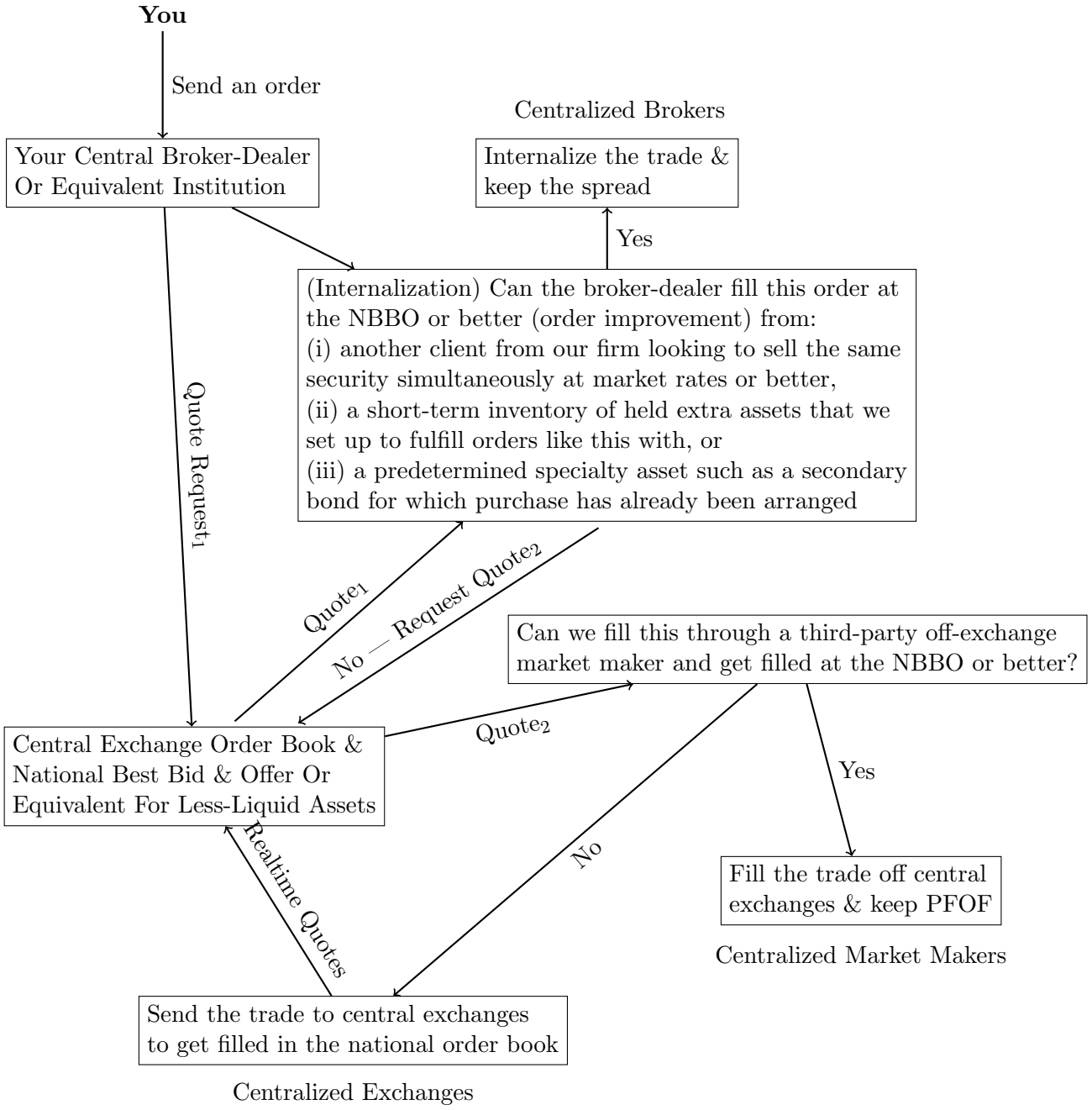


Diagram 2: Inefficiencies Of Execution In Centralized Markets

Here we can see that there are *at least* two chances for brokers to profit (and save costly central exchange fees) by sending order flow away from actual "marketplace" buyers and sellers for the benefit of centralized broker-dealers. This fulfilment pattern in turn incentives brokers to, on average, give worse trade prices than in a perfectly peer-to-peer decentralized market without intermediaries. Furthermore, because a great deal of trades occur outside of central order books due to these incentives, the central order books receive significantly less volume which in turn creates much a larger deviance in spreads and effectively leaves many assets with an inaccurate public view of investor sentiment. In effect, the NBBO or equivalent are shortchanged reported trades, data that could move the market if opaque orders made it to public order books. This has a trickle-up affect on asset pricing since those watching the spread are likely actively trading the underlying, and a decrease in their confidence of price accuracy decreases the number of "makers" and thereby overall liquidity in assets (which turns up in inaccurately publicly-published volume numbers. When these order books are further manipulated by adversaries who take advantage of especially high amounts of internalization (as in some cryptocurrency exchanges), it becomes possible to easily fake trading volume as an institution trading back and forth between yourself due to low or no competitors able to arbitrate markets since they are filled off-exchange.

3.3.1 Dark Pools

This diagram ignores dark pool high-block transactions which occur primarily through specialized ECN submissions to artificially-masked institutional order books where buyers and sellers never publicly reveal their intention to trade an asset (and very often execute block trades outside of the NBBO range outside of public oversight). We will discuss implementation of this technology in decentralized order books for institutional use in Execution.

3.3.2 Partially-Distributed Markets

This execution incentive pattern primarily impacts market trades or very close-to-spot limit orders which are able to be routed through alternative execution venues. For limit orders reasonably away from the last price of any liquid security, your chances of making it to centralized exchange order books drastically improve. Ditto for option, futures, cryptocurrencies, etc. However, note that ***most* current cryptocurrency brokers function like any other forex broker: they simply match buyers and sellers in a peer-to-peer centralized order book** and take a cut from global exchange spreads or at execution.

3.4 Lasting Impact

Before looking at how centralized financial markets fill your orders, it is vitally important to understand how central order books and time and sales work. Order books stand at the center of all financial markets because they publicly declare what the market is currently willing to pay for any given asset, a herein. Without knowledge of how the market currently values a, there is no chance for orderly, widespread financial markets. The more price discrepancies between exchanges, order books, or other sources of liquidity, the more fear and uncertainty in a market. This results in higher spreads and often scares away new investors when they see headlines about institutional price manipulation, high-frequency

traders leveraging nonpublic advantages, etc. The effects of centralized order books and their subsequent "big player" mental harm on investors is seen hundreds of millions of times daily when potential investors in the American economy second-guess the thought to invest in assets that could *change their entire financial future* because of headlines reading "800 Mile Cable Connecting CME & NYSE Lets Institutions Beat You To The Stock," "Congressman calls for SEC investigation of Gilead about possible coronavirus drug after plotted release," or "Ackman warned 'hell is coming' then pocketed $2 Billion while traders closed bets against markets." **The effects of a bulk of bad players in financial markets comes from the centralized nature of current order books.** Individuals and retail investors at large are constantly seen as "less than" the big players and almost always unable to trade with the same tools and execution venues of institutions.

Centralized order books encourage large-scale central consolidation. Firms compete tooth-and-nail to rent out the back of the coffee shop next to the NASDAQ so their orders reach the exchange a microsecond faster. This is obviously unfair to individuals and especial global investors that are often systematically pushed away from American financial markets. Billions of people do not have bank accounts, and even more will never be US citizens. Why should that stop them from sending an order into the floor's order book so that they can invest in themselves by accumulating assets? The sheer amount of middlemen it takes to get to central exchanges alone methodically deprives billions of people annually from investing in financial markets due to (i) complexity in setting up investments or (ii) physical individual political inability to trade financial assets. These two problems stem exclusively from the centralized nature of asset management and thus centralized order books. There is no difference between an unfilled American trade and an unfilled Japanese trade when they hit the order book, so why should there be such a large difference in the process these demographics go through to access financial markets? Furthermore, how do regulations in one country affect the portfolios of investors around the world, yet those same investors have no say in the policies governing the company underlying their investment? These are just some of the regular inefficiencies in centralized markets that stem from an inability for all global investors to (i) simplistically invest in a wide range of financial assets, (ii) swiftly and easily value and trade their current investments, and (iii) participate in shareholder voting simply and efficiently. In the end, these factors of centralized markets cause fundamental psychosocial rifts that push masses of people away from financial markets.

4 Decentralized Order Books

Decentralized order books are different than traditional trade execution. Rather then relying on large, complex, inter-weaved financial institutions, decentralized order books rely on collective and synchronized quorum slices to maintain network validity and execute trades. For instance, take an example network consisting of 12 nodes.

In an ideal world, say Ivan wants to initiate a trade to sell an asset a in a trade W. The first thing Ivan ought do is broadcast his intention to trade to all parties in his quorum as show in the network where W_{init} is the equivalent of an unfilled trade:

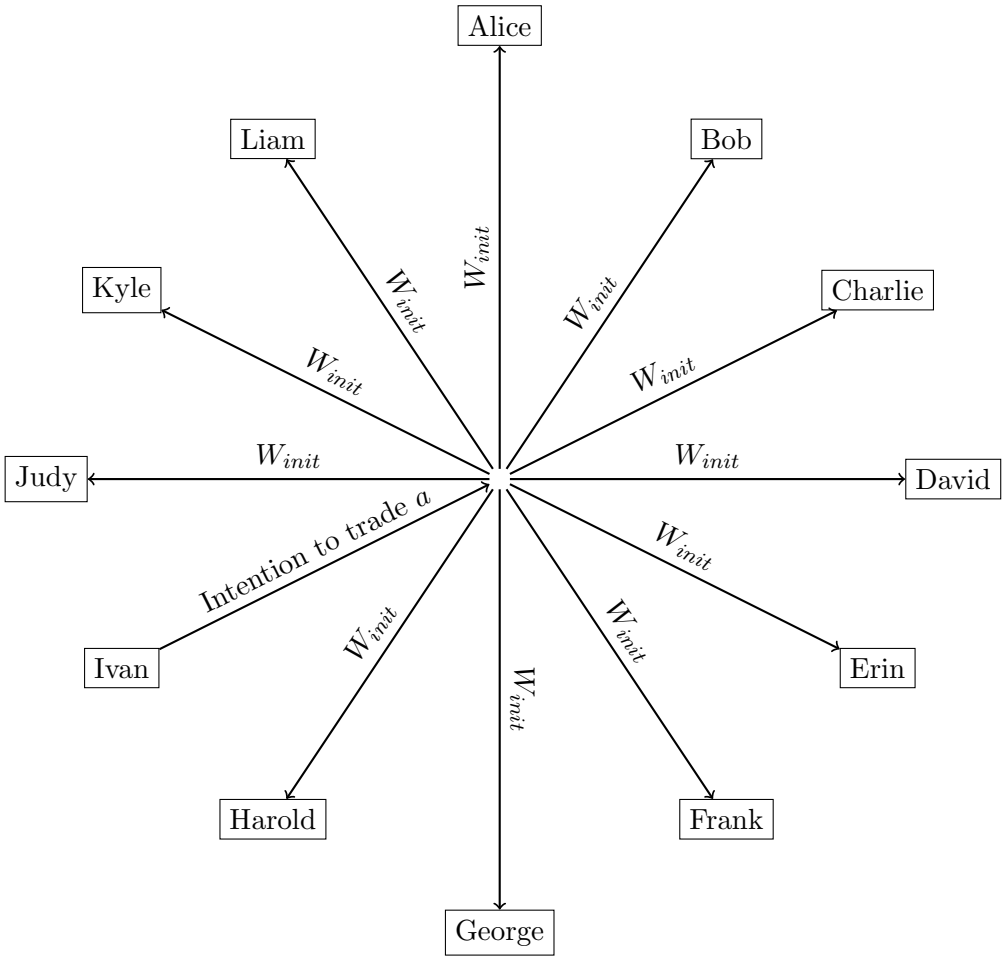


Figure 1: Broadcast Trade To Peers

For W to fill, someone else in Ivan's quorum slice must take the other side of his trade. In the fastest market possible, W_{init} would fill instantly by an opposing trade in some decentralized pool of trades known by everyone waiting to fill, a decentralized order book. This order book should be constantly known by all participating nodes and updates instantaneously when new, validly-signed transactions such as W are propagated in the network. With this method, all orders can then propagate across different quorum slices until some other trade fills the original W_{init} which is signed by Ivan s.t. anyone who wants to fill the trade can directly transact with Ivan. Ivan's order ought trade with and sign a transfer and asset transfer with the first peer willing to transact at his (limit) price or within the (market) NBBO as defined by the globally-synchronized decentralized order book.

After execution, the time and sales from the order book and subsequent last asset price are observed and updated by all decentralized by network participants according to the following Figure:

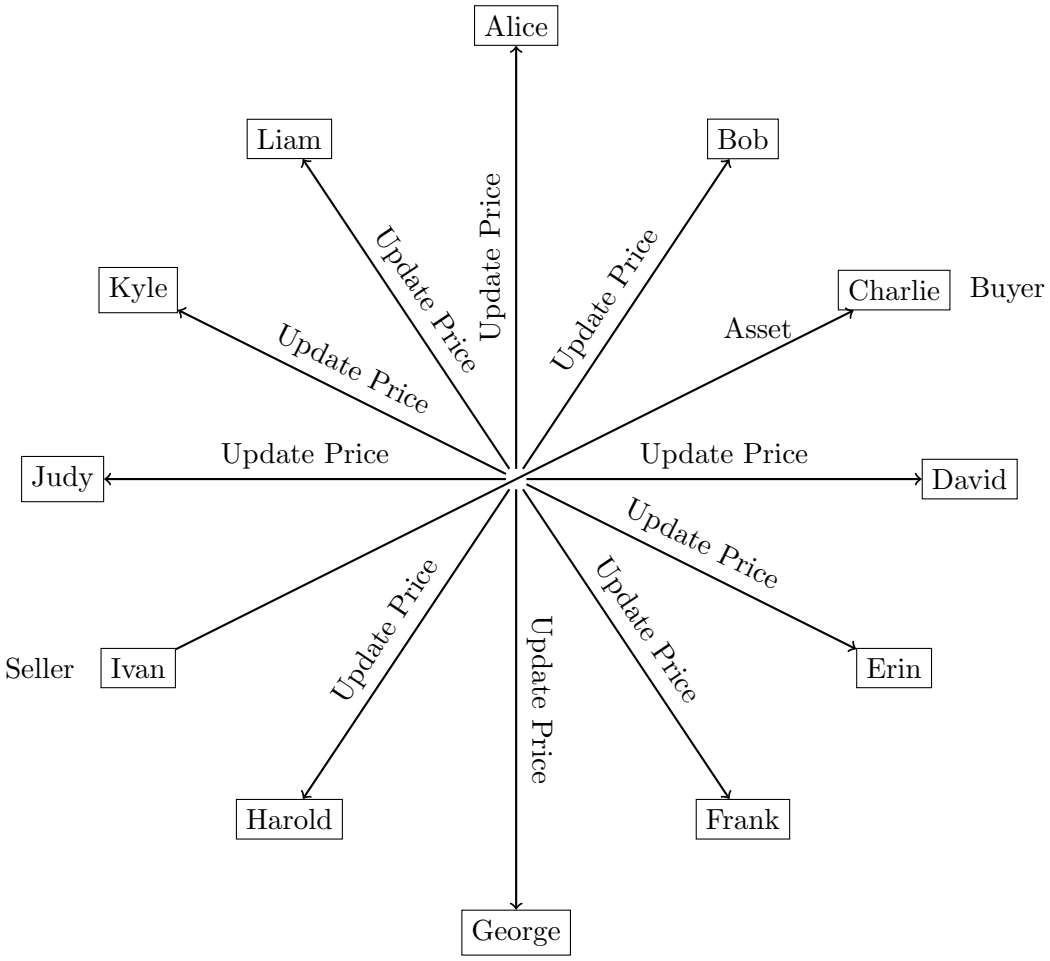


Figure 2: Peers Observe & Record A Filled Trade

In contrast to centralized order books, this recordkeeping process relies on complete transparency between decentralized nodes. Because peers directly transact with one another, there is also a complete removal of conflicts of interest between parties looking for fills. Give all semi-honest network participants in a federated byzantine network, nodes have no collective incentives to challenge authorized trades from the order book. This transparency and ease of accurate collective books ought create extremely effective financial markets.

However, some nodes may not be connected to or observing the network. Additionally, some nodes may just be coming online ∴ we ought propagate full trade time and sales alongside decentralized order books for accurate records (to all full nodes). This process works when each node fully propagates broadcast trades and unfilled orders after locking in quantity and price agreement ∀ assets according to the following Figure:

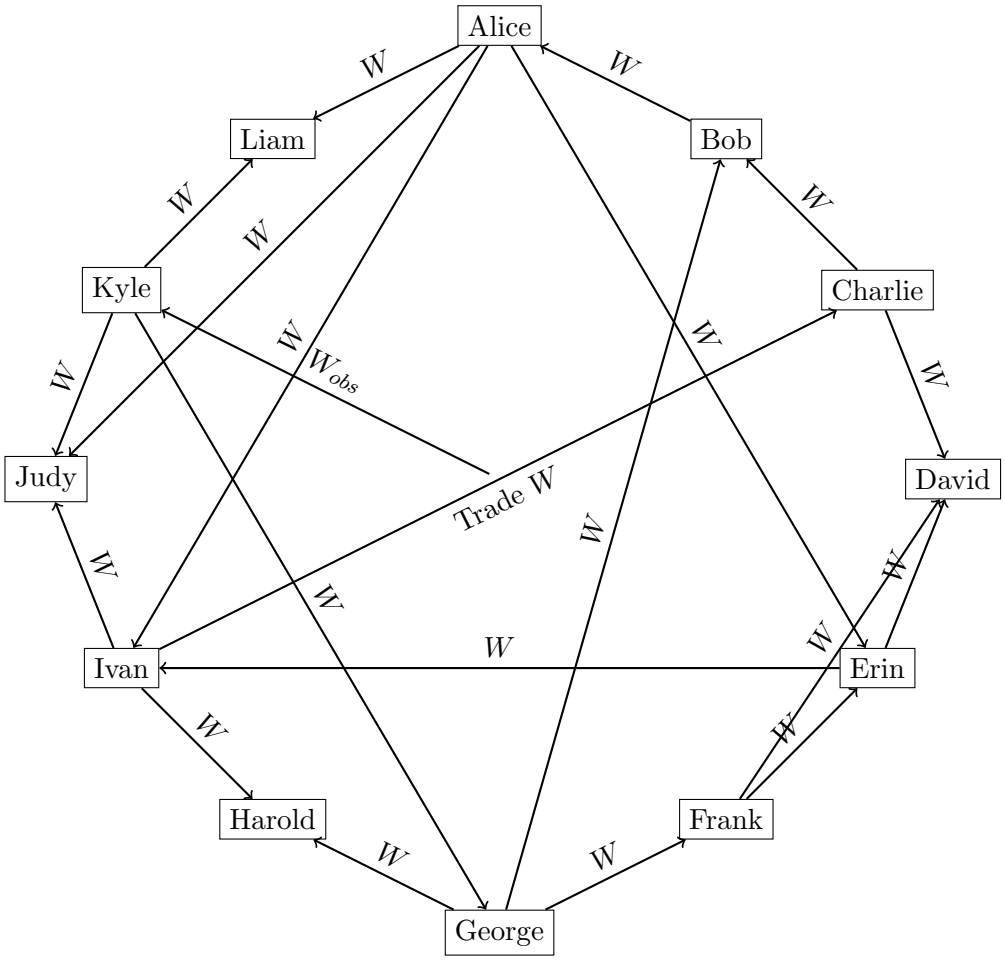


Figure 3: Nodes Propagate & Validate Trades

This is essentially the most important part of decentralized order books: total synchronization. At first, Ivan and Charlie propagate W as the counterparties in W s.t. neighboring peers know about the transaction. These semi-honest peers then propagate the trade to nearby peers based on the information from trade initializes. **This trade sale must be verified by W which has two signed participants,** and these peers can then continue sending W on throughout the network.

Furthermore, peers such as Kyle can observe the actual signed trade W and propagate this information alongside all other confirmation of W over time. These W_{obs} increase trade-recognition speed while requiring active network monitoring. This could help some parties spot large filled trades from the order book marginally faster than other peers, incentivising peers to actively monitor the network for trades to verify. Note that none of this verification impacts the actual trade which occurs cryptographically through the decentralized order book when two parties both sign a trade and exchange assets (maximizing trade speed). The multiple rounds of confirmations are simply used to maintain network validity and prevent double spends. These confirmations create and maintain a blockchain record of asset ownership which can be easily publicly audited and used for settlement and regulatory reporting.

5 Why Decentralize Order Books?

Incentives.
Centralized order books are exceedingly fast, proven, effective, scalable, and reliable. For decentralized order books to viably replace centralized order books, they MUST replicate the speed, history, effectiveness, scale, and reliability of current infrastructure. Given these prerequisites, the authors believe decentralizing order books are the inevitable *future* of financial markets because they:

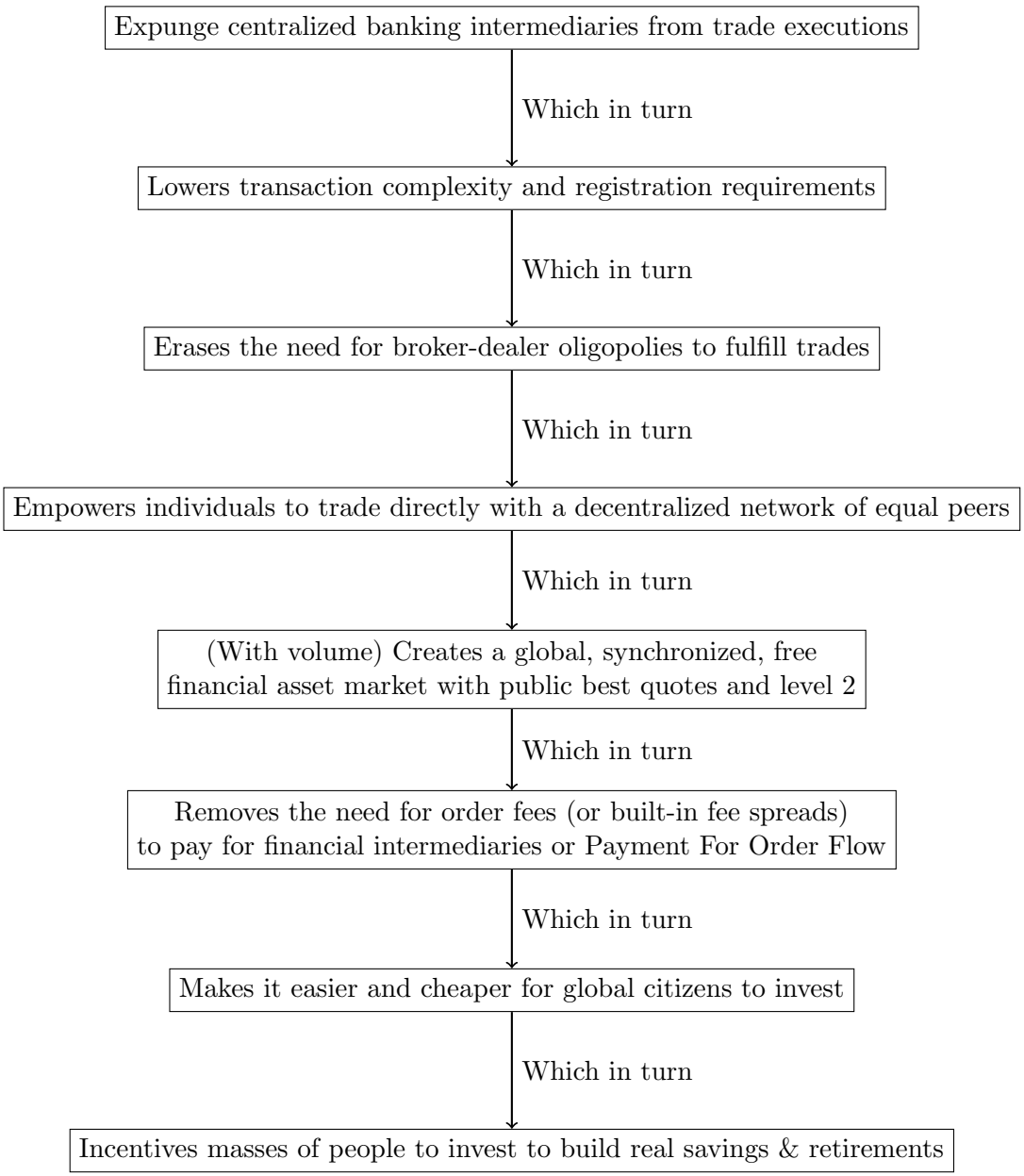


Diagram 3: Incentive tree for decentralized order books

$\forall$ these reasons, we propose a protocol to facilitate decentralized order books for global financial markets.

6 Our Protocol

We looked at a number of the Decentralized Exchange protocols currently available, and chose two of them to analyze more closely: The 0x Protocol and Stellar's native decentralized exchange. Both of these protocols allow for the exchange of various assets without requiring a centralized authority to process them.

6.1 0x Protocol

The 0x Protocol is a series of smart contracts deployed on the Ethereum blockchain. It allows the exchange of both ERC20 and ERC721 tokens as well as combinations of either kind. Orders are created using the smart contracts, which can then be sent to either a Relayer or broadcast on the 0x Mesh network. Relayers allow users to view all of the orders sent to them, so that they can create corresponding fill orders using the 0x smart contracts. the 0x Mesh network is an alternative to using Relayers as well as a way to increase their effectiveness. Individual users can run Mesh nodes to broadcast and receive 0x orders, and Relayers can connect to the mesh network to share orders with other connected Relayers as well as receive orders broadcast by individual nodes.

6.2 Stellar

Unlike the 0x Protocol, decentralized exchange is not accomplished through smart contracts in Stellar because it is built into the protocol. The record of orders is kept completely on the Stellar ledger, and there is no need for external Relayers or a Mesh network like in 0x. The Stellar order books can contain transactions for any Stellar Asset, which have a more complicated definition that is out of the scope of this analysis. However it should be noted that they can be representative of any physical items, whether it be USD or a bundle of bananas.

6.3 Orderbook Location

One of the most important differences between the two implementations of decentralized exchanges is where the orders are located. In 0x, they are kept off of the Ethereum blockchain, however in Stellar they are kept entirely on chain. Both of these designs have trade-offs, and there are pros and cons to each.

6.3.1 Liquidity

A benefit of the Stellar order books being built into the protocol is that it does not require a secondary network to function. This gives the order books all of the liquidity of the Stellar network, whereas the 0x Protocol only has liqudity from its own mesh network.

6.3.2 Filling

Another benefit of the Stellar implementation is that filling orders is done automatically as part of the protocol. The 0x Protocol requires filling existing order explicitly. Platforms that utilize the 0x Protocol will likely not allow someone to create an order if it could fill an existing order. However, that matching must be done by a Relayer or by individual users filling open orders. In contrast, when Stellar orders are submitted they will fill any open orders that they cross, and therefore knowledge of existing order is not inherently required to create orders on Stellar.

6.3.3 Making Changes

One of the major benefits to writing the 0x Protocol using smart contracts is that they are very easy to update. New smart contracts can be deployed with bug fixes or updates much easier than on Stellar. While small changes could be deployed to either protocol with a similar ease, larger changes to the protocol or the format of orders would be significantly harder for Stellar. Since the order books are built into the protocol, breaking changes to them would require a hard fork of the whole Stellar network. Meanwhile, breaking changes to 0x would only require a "hard fork" in the 0x Mesh network, which is significantly smaller than the entire Ethereum chain.

7 Risks

7.1 Timely Settlement

In order to effectively implement decentralized order books, all trades must execute as close as possible to immediately. Therefore the best protocol should have minimal confirmation times. With that said, it will certainly take a significant number of participating peers for a protocol to reach maximum efficiency. Furthermore, we must have a critical mass of participating companies and clients to create sufficient liquidity for decentralized order books. We believe that once an initial minimum base of peers is acquired, scaling up decentralized order books ought be a straightforward process that increases the effectiveness of the protocol through the network effect. We will talk more about recruiting companies in What To Do Now. As for increasing the number of client peers, any attempt to have a decentralized protocol become the standard should begin with the use of that protocol alongside centralized order books as an alternative trading system initially. It should fulfill orders alongside centralized order books until a critical mass of supported decentralized order book assets and peers is reached. Think of Netflix starting out by licensing old movies before making original content.

7.2 Counterparty Risk

We require complete ownership of any asset before a trade is made in Execution. This should get rid of essentially all semi-honest delinquent-trade risk assuming atomic swap execution or equivalent after trades are matched in the decentralized order book ∴ We assume that transactions could only fail after valid confirmation due to an attack on the

underlying consensus network. With that said the purpose of this paper is to establish decentralized order books, and we will talk about trade fulfillment and settlement in What To Do Now.

7.3 Spreads

Spreads are tight in traditional financial markets in a very large part because of third-party market makers. Market maker participation is crucial for the success of decentralized order books. By opening up access to order books globally and essentially eliminating the centralized geographical advantages of certain firms today, we believe more market makers will enter decentralized financial markets in the long term seeking arbitrage and low-risk investment opportunities, thereby increasing liquidity in decentralized order books and keeping spreads tight. Furthermore, we've implemented a much tighter tick size definition that most financial markets in Execution that promotes market-making in lower-priced assets due to increased fiat equivalent decimal points. ∀ These reasons, the authors believe highly-adopted decentralized order books will be more liquid than traditional centralized order books with tighter spreads. This metric must be constantly measured and focused on in practice.

7.4 Malicious Adversaries

Investor protection in decentralized order books is paramount. Our protocol's implementation must perform the role of order books securely, accurately, and quickly. We rely primarily on the sustainability and assurance of the underlying blockchain network outlined in our protocol to protect the validity and transfer of assets in decentralized order books. All nodes rely on a byzantine majority agreement on trade history once matching occurs in the order book. **Assets are only 'digitally swapped' between parties to the extent that the network agrees on this settlement.** By following the longest chain, we expect decentralized order books to stay secure and accurate to the extend that the underlying cryptographic protocols are valid ∴ decentralized order books are strong and trustworthy as long as no attacks on the underlying protocol work. Decentralized order books can withstand malicious attacks even at scale assuming our proposed protocol uses only secure cryptography, blockchain networks, consensus methods, etc. The failure of any of these underlying protocols could render short-term transactions invalid. We do not think this is a large risk given the security of the protocols used.

7.5 Crash Failure

Definition A server halts, but is working correct until it halts.

Small number of node failures should have minimal impact on the ability for anyone to create or fill orders since there is no independence on individual nodes in a decentralized system. If a Relayer were to go down in the 0x Protocol, it could impact orders that are known exclusively to that Relayer but ideally the Relayer should be broadcasting submitted orders on the 0x Mesh network. In Stellar, miners crashing would also have very little impact on the order books as a few nodes would have very little impact on the network as a whole.

7.6 Omission Failure

Definition A server fails to respond to incoming requests.

In a centralized exchange, orders being filled slowly or not at all could benefit the centralized entities, however in a decentralized exchange the incentive is lessened. In the 0x Mesh network or Stellar scenario, orders are broadcast to other nodes so a small number of nodes could not omit orders/fills since they would end up broadcast anyway. Relayers could potentially omit orders to prevent them being filled, however users of that Relayer would be less likely to use that Relayer in the future if their orders are omitted from being broadcast. The same logic applies to filling orders.

8 Execution

8.1 Time

Network time and transaction timestamps ought be synchronized with New York time daily at midnight according to National Institute of Standards and Technology requirements $\forall$ participants. Clock synchronization throughout the day (and especially near the open and close) under any network stress state are essential for an orderly market. Failure to achieve standardized time and speedy reporting jeopardizes all validity of decentralized order books. Trades must be accurately reported and publicly known instantaneously for valid price action.

8.1.1 After-Hours Trading

The authors also propose that all assets be tradable at any time through decentralized order books when there is a made market, with **significantly higher** incentives for nodes to support a swift and accurate order book during market hours. We will explore these incentives further later through a fulfillment mechanism. The import time concern here is that, assuming peer-to-peer participation, decentralized order books do not close. Orders can be submitted and filled at any time.

8.2 Tick Size

Equity tick sizes ought be automatically determined roughly along the lines of the following chart (adjust for international local equivalent).
These tick sizes assume trades in fiat USD or USD valuation equivalent. For cryptocurrency-based trades tick sizes are determined by the underlying currency. When money is exchanged for assets in a final transaction (once an underlying price and quantity is agreed upon), trades round up or down to their nearest penny increment (up if $total \geqslant \$0.005$ or equivalent) if executed in fiat.[2]

[2]This contingency depends highly on which currency underlies a trade

Asset Previous Rolling 30-Day VWAP	Tick Size
$0.00 to $0.05	$0.00000001
Above $0.05 to $0.10	$0.0000001
Above $0.10 to $0.20	$0.000001
Above $0.20 to $0.40	$0.00001
Above $0.40 to $4	$0.0001
Above $4 to $25	$0.001
Above $25	$0.01

Table 1: Asset tick calculations based on closing prices

8.3 Listing Requirements & Integration

8.3.1 Established Assets

The first step to adopting decentralized order books is moving already-traded a from traditional centralized transfer agents to decentralized order books. These books must stand up to federal accounting regulations and fulfill any roles a traditional transfer agent is regularly expected to perform, included but not limited to:

1. **Ownership reporting** Decentralized order books must keep track of who owns any particular asset a alongside the quantity their public identity controls. This requires further implementation of accounting and sufficient bookkeeping to maintain a distributed, public, consensus-based, append-only ledger of ownership. This ledger must publicly (i) identify top shareholders and (ii) be usable to report insider trades alongside Form 4. See What To Do Now for more on this record-keeping technicality.

2. **Stock splits** Decentralized order books (and subsequent share registries) must have a consensus mechanism in place for (i) companies issuing stock to declare stock splits, (ii) the market validating a stock split requests' authenticity, (iii) agreement on the stock split time, and (iv) uniform implementation of the split ratio as defined by the parent company.

3. **Interest payments & dividends** Decentralized order books must facilitate dividends to the public addresses of investors listed on the ledger of ownership previously discussed. Plus, these books must enforce interest payments on traded debt to the asset owner or declare a company insolvent if they stop paying. (Alongside reporting necessary tax implications of transactions for all assets)

4. **Collateralized bond & preferred share recording** Decentralized order books must differentiate different kinds of assets from one another based on differences between similar but not fungible assets (primarily collateralized debt or other forms of preference in the case of insolvency & share classes with different voting weights).

5. **Shareholder voting** Decentralized order books must record which public asset-holders control the voting power in any given underlying investment & enable shareholder participation in public and regularly-scheduled regulatory shareholder meetings.

8.3.2 New Assets

After established financial assets are traded on decentralized order books, the next step is to empower new assets to be issued in and valued by the market. These new assets must follow local registration and regulatory laws in their respective territories. The authors will further discuss this legal complexity in What To Do Now. Aside from legal requirements, a simple consensus of the decentralized network is all that should be needed to issue a new asset. This is a technical complexity that requires implementable testing to ensure that new, valid firms can enter tradable markets (while consensus-deemed invalid assets are kept out). Because issuing new assets requires so much regulatory oversight, we will further discuss issuing new assets in What To Do Now. The centralized legal repercussions of these actions and potential for fraud and manipulation go outside the realm of this paper.

8.4 Block Trades

By default, an order sent to a decentralized network $\forall$ **assets**, a herein, at any **price**, p herein, not immediately filled "at market" is publicly available in a single decentralized record of open orders in the order book. These orders can originate from an individual (or firm) through any consensus means necessary, but they will have no associated exchange execution route since all orders are filled from peer to peer once matched, either partially or fully. Given buyers and sellers asking for the same p of fungible a, trades will go through the best execution route as determined by **a fulfillment mechanism**, m herein.
$\therefore$ The only way to commence block trades for large amounts of a is to pre-arrange transactions at an established p off-chain and then transact on the network publicly in real time. We propose the use of Multi-Party Computation hash functions through decentralized order book consensus networks to facilitate these trades. The extent and technical details of this implementation are outside the scope of this paper. This protocol will be based on the card-hiding handshake algorithm s.t. anyone can execute dark pool trades in which a peer can submit a hidden bid at a hidden price for a public lot. Similarly, a seller can submit a hidden ask at a hidden price for a public lot. All of these trades can be held in dark liquidity for the sole purpose of increasing trade execution ability for block trades. Trade costs, speed, trust, counteryparty risk, execution speed, etc. should remain the same with all else equal. Two parties can either make a trade at a price or not, and peer arbitrage will keep dark markets liquid with sufficient participants submitting potential low bids and high asks relative to the NBBO to ensure submitted orders at reasonable market level are not easily predicated despite hidden prices s.t. the transaction can be executed without necessarily informing the public or abiding by NBBO for large blocks of shares (very specific implementation use cases). A similar method will also likely be implemented for ETF creation/redemption blocks.

8.5 Circuit Breakers

In equities, price-based circuit breakers must be instantaneously enforced by m based on the last trade price of an asset outside of SEC circuit-breaker levels for over 15 seconds.[3]

[3] **Investor Bulletin: Measures to Address Market Volatility**

Furthermore, regulatory-based or news-based halts must be enforced by a consensus vote established in m, which will be further discussed in What To Do Now.

8.6 Options

Options ought trade on decentralized order books just like traditional unleveraged investments. Traditional centralized equity options contracts have (i) exchange listing requirements, (ii) share-price minimums, (iii) float minimums, and (iv) shareholder minimums. Other asset options are discussed below. $\forall$ equity options, the authors propose the ability for anyone in the decentralized network to submit bids and asks for option contracts at any expiration on any investment at any time.

8.6.1 Expiration Dates

Because anyone can submit orders to buy and sell any expiration option at any time through decentralized order books, there will be significantly more expiration dates for options contracts on underlying assets. Assuming there is a market for the date of option expiration and strike, buyers and sellers can meet and sign contracts. The authors believe that a small number of expiration dates will attract a majority of trading volume. $\therefore$ While some speculative investors may, at first, trade nonstandard expiration dates, we believe that contracts in the long-term will stabilize around standard expirations with the greatest volume. This volume incentivizes orderly trading since nonstandard positions will likely have extraordinarily high spreads and difficult-to-define time value and subsequent Greeks.

8.6.2 Expiration Executions

In-the-money contracts will automatically execute the option agreement between the final buy-side and write-side holder of the option at 4PM New York time as defined by decentralized order book network per the Time section above.

8.6.3 Contract Tick Size

Because we are proposing options trading on any a with a sufficient market to support contracts, we will use the tick size calculations presented above in Table 1. In the case of new public assets with less than one day of trading history, the tick size ought be \$0.00001 with final transactions rounded to the nearest cent, as defined previously (this edge case ought also apply to the underlying asset tick size for brand new assets).

8.7 Standard Currency

The underlying standard currency for decentralized order books ought be the coin native to the protocol which can then be translated into preferred domestic on a peer-by-peer basis through instant client currency rate exchange representations (with exchange rates coming from the last price of currencies from decentralized order books). Most assets will be held in their native anchor in the Stellar network, for example.

8.8 Fractional Assets

For fungible assets, we propose the ability to enter trades in any investment with fractional quantity where the number of decimal points for an asset is the same as tick sizes defined in Table 1 (low-volume options order books may prove unused, which is okay). For equities, this simply results in the trade of fractional shares across decentralized order books which simply use the decimal system for trades. Ditto for futures. This implication has little effect on forex or cryptocurrencies. As for options, we propose that fractional options represent subsequent fractions of the underlying. In terms of equities, we propose that, for example, a quantity of 4.2069 contracts controls the right to 420.69 shares of the underlying per the equation where l for stocks is 100 shares per options contract:

$$4.2069 * l = 420.69$$

In terms of futures, commodities, and other derivatives, we apply the same arithmetic, replacing l with the specific instruments' l_0.

8.9 Margin

To enter bids or make a trade in any way whatsoever, you must have the entire public account value needed to complete any trade. This means that decentralized order books effectively act as debit recorders of transactions and trade proposals. Once a trade is executed, its full market value must be exchanged between buyer and seller immediately.

8.10 Futures

Futures ought be traded just as any other asset in decentralized order books. As defined in Margin, this means that the full value of a contract must be held by investors to debit when they want to make a trade.

8.10.1 Commodity Fulfillment

Contracts for physical commodities ought not be delivered and rather settled for cash at expiration (or on the last trading day). Physical fulfillment through decentralized order books requires the transfer of sensitive personally-identifiable-information. Furthermore, there is no straightforward way to synchronize global decentralized physical commodities holding facilities. The only thing buyers and sellers ought need to know about each other are public keys and trade price.

8.10.2 Initial Margin

Because of a lack of margin for contracts, the initial margin requirement is the entire contract value.

8.10.3 Maintenance Margin

There is no maintenance margin for fully-funded contracts.

8.10.4 Futures Contract Tick Size

Futures contract tick sizes ought mimic those defined in Table 1.

8.10.5 Options Contract Tick Size

Futures contract tick sizes ought mimic those defined in Table 1.

8.10.6 Credit Markets, Default Swaps, & Nontraditional Securities

Credit markets, default swaps, and other are traditionally difficult-to-exchange securities ought be tradable through decentralized order books given an asset and market participants. Implementing the trade of these securities and ensuring little to no counterparty risk must be done on a per-security basis, especially for assets requiring premium payments. Decentralized order books can then be used to trade issued assets.

9 Conclusion

In this paper, we've focused on facilitating asset trades across the world instantaneously though independent peers in a decentralized order book. We've seen the inefficiencies of centralized order books (and subsequent asset exchange) and proposed a solution similar in function to the SMTP protocol on federated Byzantine agreement systems used to publicly receive, report, and verify trades. The purpose of our protocol is to lower trade costs and inefficiencies while increasing global access to financial asset markets.

10 What To Do Now

10.1 Sufficient Honest Consensus

The first step of implementing decentralized order books is achieving majority consensus implementing our protocol. Once over two thirds of nodes are reliable and honest parties, we should be able to reliably execute trades with six-block verification on the network. At scale, the ideal time to verify trades out be seconds with settlement occurring as soon as possible.

10.2 Settlement & Fulfillment Mechanism m

Once trades are filled in decentralized order books, they must go through settlement s.t. the buyer and seller actually exchange the underlying assets posted in the trade. In centralized markets, this occurs through an outside third-party settlement house. We propose that asset transfers be recorded, validated, and maintained on a public blockchain. The details and implementation of this settlement protocol are outside the scope of this paper.

10.3 Standardized Global Shareholder Meetings

All publicly-recorded shareholder of any given enterprise ought be able to vote on behalf of the shares they own at corporate meetings (or declare their vote equal to some other

trusted shareholder's). We proposed the ability to send votes for shareholder who want to participate in corporate governance through the issuance of single-use voting tokens issued by the underlying company to all shareholders in proportion to the amount of shares they control shortly before the commencement of a regular meeting. These tokens ought have nominal value, but the holders can send them to destination addresses for voting s.t. a particular proposal may have one 'yes' and one 'no' address where shareholders can send their voting tokens to for a reasonable specified time period to vote on particular topics. After a define date range, these tokens can simply disappear valueless. Implementation of this protocol would come after direct decentralized transfer-agent integration, discussed below.

10.4 Regulation & Local Laws

All assets (most importantly new assets distributed to American investors) must follow local registration and regulatory laws. There are many legal complexities to this integration for decentralized order books. Namely, decentralized order books are borderless by nature, but sale of securities across state borders is highly regulated and has potential reporting and government monetary impact s.t. many regulations are in place that specifically slow down or hinder the international trade of non-currency assets ∴ We propose that decentralized order books execute all transactions as if each party were part of the same governing agency s.t. no international regulations are immediately applied to the protocol which is only run, executed, and trusted by the good faith of its peers.

10.5 News-Based Or Regulation-Based Asset Halts

Because there is no central exchange in decentralized order books, it is particularly difficult to enforce news-based or regulatory-authority-based halts. Any given malicious adversary could impersonate a central regulatory authority and issue false news halts on stocks at any given time to create market disorder should central power be given to any agency ∴ We propose that regulatory-based or news-based halts must be enforced by a consensus vote established in the federated byzantine network by peer agreement. We understand that this may slow the potential halt of particularly notable companies in light of major financial news, but we see this as the most effect way to enforce decentralized non-price-band-based halts and believe that a majority of semi-honest nodes will accept and support a legitimate halt request without allowing for abuse.

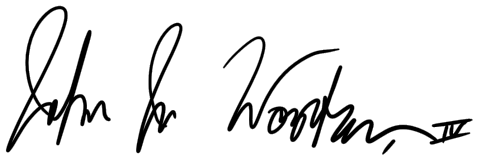
10.6 Central Recognition

Due to the nature of trades, we do not believe that decentralized order books need central recognition to operate and facilitate orderly financial markets. Since trades occur between peers participating in the network (and the network is based on our decentralized protocol), the only thing needed for liquidity, execution, and accurate bookkeeping is enough network peers. Furthermore, network peers seeking transparent execution can directly bring in their assets by simple marking them (specifically equities) as held in the street name of decentralized order books, thereby irreversible decalring the asset held on decentralized order books (since no central party controls the street name of decentralized books which in

themselves maintain a decentralized blockchain ledger of ownership infromation). By this logic, investors can similarly stake liquidity in assets not yet listed directly on decentralized order books.

10.7 Peer-To-Peer Viewable Transfer Agent

Perhaps the most important next step in facilitating decentralized order books is acting as the stock registrar for existing American public companies. Registrar services, as referenced in Background Information, are moderately hefty expenses for any reasonably-sized company. We've proposed using decentralized order books (and subsequent public decentralized blockchain account ledger records) to keep track of shares. This fulfills all the operational and regulatory requirements of a stock transfer agent to perform necessary distributions, splits, etc. ∴ Our first step is to migrate Snap Inc.'s shares onto decentralized order books, effectively saving them an estimated $78,374 annually while increasing shareholder liquidity and trade performance.



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